erty owners can evaluate whether solar makes sense for their buildings. Chapter 4 explains how Bostonians can use the Solar Boston map to further explore the solar potential of their homes or businesses. Chapter 5 details state and federal financial incentives that may be available to owners of solar systems and Chapter 6 details how to find a qualified solar installer. Chapter 7 describes the permitting and interconnection process for systems built in Boston and is intended to serve as a primary resource for solar installers working in the city.

Chapter 2. Solar Energy Technology Background

This section provides an overview of solar photovoltaic (PV) technologies and systems. The reader is encouraged to review the **Additional Resources** listed at the end of this section to delve deeper into many of the topics presented here as well as the **Glossary** at the end of this guide.

2.1 How Does a Photovoltaic System Work?

Photovoltaic systems convert sunlight directly into electricity. These systems allow building owners to generate some or all of their daily electrical energy demand either on their roof or somewhere on their property. The majority of solar PV systems are grid-tied, meaning they are directly connected to the power grid and do not require battery storage. Grid-tied PV systems will generate electrical power to supply part of a building's energy usage during the daylight hours, but will not produce power during a power outage or during non-daylight hours. Figure 2.1 depicts an illustration of a solar PV system interconnected to the grid.

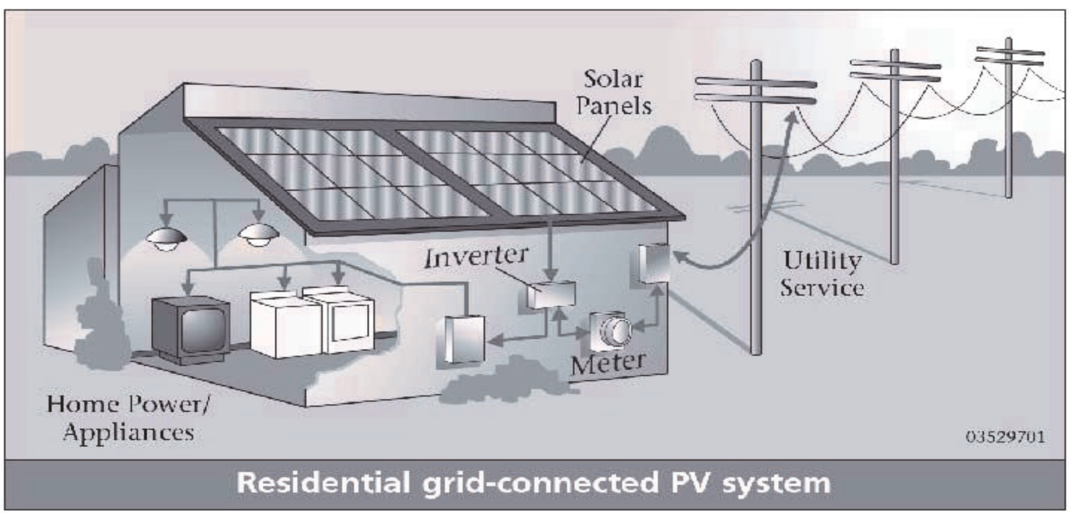

Figure 2.1: Residential Grid-Connected PV System. Source: A Consumer's Guide: Get Your Power from the Sun, US. Department of Energy, 2003

A solar PV system can provide power to a home or business, reducing the amount of power required from the utility; when the solar PV system power generation exceeds the power needs, surplus power can be fed back into the electricity grid, spinning the building's electricity meter backwards. The ability to export electricity into the grid and receive compensation from the utility is called **net-metering**. NSTAR has a special rate tariff for net-metered power system and will install a special utility meter that records the net power coming in from the utility and the surplus power flowing out from the solar PV system. For more information on net metering see Chapter 5 of this guide.

A solar PV system will not operate during a power outage unless the system includes a battery backup. During a power outage, photovoltaic systems can energize electric lines that the utility assumes is not energized, and create a shock hazard to personnel. Photovoltaic systems will shut off during grid power outages as a safety feature for utility personnel who might be working to restore power on nearby electric distribution lines. Photovoltaic systems can also be designed with battery backups to provide uninterruptible power supplies (UPS) that can operate selected circuits in a building for hours or days during a utility outage.

The basic building block of PV technology is the solar cell. Solar cells are typically six- to nine-inch wafers of silicon or other advanced materials with integrated circuitry. When sunlight hits a solar cell, the unique chemistry of the cell materials generates an electrical current. Multiple PV cells are connected to form a PV module, the smallest PV component sold commercially. A PV system connected or tied to the utility grid typically has the following components:

PV Array: A PV Array is made up of PV modules, which are collections of PV cells. The most common PV module is 5-to-25 square feet in size and weighs about 3-4 lbs/ft^2. Modules range in power output from about 10 to 300 watts (although higher wattages are available for utility-scale PV applications), with the power density ranging from about 5-to-18 watts per square foot.

DC to AC Inverter: An inverter is the device that takes the direct current (DC) power from the PV array and converts it into standard alternating current (AC) power used throughout a building. The inverter also creates an AC power stream that matches the frequency and quality of power from the electricity distribution grid. This power conversion process allows PV generated electricity to be exported onto the power grid.

Balance of System Equipment (BOS): BOS includes mounting systems and wiring systems used to integrate the solar modules into the structural and electrical systems of the building. The wiring systems include disconnects for the DC and AC sides of the inverter, ground-fault protection, and overcurrent protection devices, junction boxes and possibly circuit combiner boxes. (See Figure 2.2).

Figure 2.2. Typical Residential solar wiring. Source: Celentano Energy Services

Metering: Solar PV systems require special meters that record and display total electricity generated by the solar system. For a typical solar installation, the local utility will assist with the installation of a suitable bi-directional electricity meter that allow system owners to net-meter installations. Many installers are also offering Data Acquisition Systems (DAS) that can be accessed through a website interface. These metering systems allow system owners to track their PV system's production in real time and to determine if their system is functioning properly. The DAS for a 19.5 kW PV system on the Franklin D. Roosevelt Elementary School can be viewed here: Roosevelt School PV.

Batteries (optional): Batteries can provide energy storage or backup power in case of a power interruption or outage on the grid. Battery backup PV systems (Fig. 2.3) account for less than 5% of all installed solar PV systems.

The photovoltaic systems discussed in this guide are generally installed on the customer's side of the electricity meter, allowing the system to offset building electricity load. Many utilities and power generating companies are currently building multi-megawatt, utility-scale photovoltaic systems. These ground mounted, multi-acre PV systems generate power that is sold in the wholesale electricity market.

Fig. 2.3. A battery bank for an off-grid PV system on Georges Island in the Boston Harbor Islands.

2.2 Photovoltaic Technologies

Today's PV systems come in a range of efficiencies and configurations. Photovoltaic systems with modules that are mounted on top of existing roofing are the most common configuration, but building integrated photovoltaic (BIPV) systems are gaining in popularity. In a BIPV system, the solar modules both generate electricity and serve as a functional building architectural element. Roof shingles, building siding and windows can be replaced with BIPV systems.

2.3 Installation Methods

There are a number of methods for affixing PV arrays to buildings or mounting them in open spaces. Common PV array mounting methods for residential and commercial systems include:

- Integral mounting (rooftop) (Figure 2.4)
- Standoff mounting (rooftop) (Figure 2.5)
- Rack mounting (rooftop or ground)
- Ballasted mounting (rooftop or ground) (Figure 2.6)
- Pole mounting (ground) (Figure 2.7)

Large-scale flat roof commercial projects are often designed with fully engineered and certified systems, and many systems require no roof penetrations. For these systems, mounting hardware is either ballasted, interlocking or some combination of the two in order to withstand wind speeds as required by local building codes. Non-penetrating ballasted systems require adequate roof structural integrity in order to withstand the additional weight of the ballast (Fig. 2.6). Ballasted, interlocking systems often limit the maximum angle that the PV array can be

Figure 2.4 Integral rooftop mounting system (attach directly to roof rafters) at the Boston Nature Center.

Figure 2.5: Standoff mounting system for roof top (several inches off the roof surface allowing natural venting) Source: Unirac

Figure 2.6 Commercial ballasted PV system on the Roosevelt Elementary School.

Figure 2.7: Pole-mounted PV system at Logan Airport.

tilted in order to withstand design wind speeds. Non-penetrating mounting hardware can be installed on standing seam metal roofs with roof clips. Mounting hardware can also be mechanically attached to the roof and underlying structural members.

Installation of PV systems requires detailed structural analysis to ensure that the underlying building can safely support the added load of a PV system. In the City of Boston, structural drawings stamped by a Professional Engineer are required to obtain a building permit to construct PV systems.

2.4 Additional Reading Material and Resources

Photovoltaic Power Systems and the 2005 National Electrical Code: Suggested Practices , SAND2005-0342, February 2005, Sandia National Laboratories, Photovoltaic Systems Assistance Center, Albuquerque, NM 87185-0753. Also available in PDF format only from the Southwest Technology Development Institute, http://www.nmsu.edu/%7Etdi/Photovoltaics/Codes-Stds/PVnecSugPract.html

A Guide to Photovoltaic System Design and Installation, California Energy Commission Consultant Report 500-01-020, June 2001 http://www.energy.ca.gov/reports/2001-09-04_500-01-020.PDF

Installing Photovoltaic Systems (Course Manual) , 2002, Florida Solar Energy Center, 1679 Clearlake Road, Cocoa, FL 32922-5703 http://www.fsec.ucf.edu

Home Power: The Hands-on Journal of Home-Made Power , Home Power, Inc., PO Box 520, Ashland, Oregon, www.homepower.com

Solar Ready Buildings Planning Guide, L. Lisell, T. Tetreault, and A. Watson, National Renewable Energy Laboratory, Technical Report NREL/TP-7A2-46078 December 2009

A Homebuilder's Guide to Going Solar, U.S. Department of Energy, December 2008, DOE/GO-102008-2744